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Kongsø, Hans Erik; Hansen, Benny Kurt

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Department of Reactor Technology
Risø National Laboratory
DK-4000 Roskilde
Denmark

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NUCLEAR DISTRICT HEATING PLANT

PRELIMINARY DESIGN CONCEPT

by

Kurt Hansen & Hans Erik Kongsø

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Abstract

A nuclear reactor for district heating is proposed. A preliminary design concept of the reactor is presented.

Emphasis has been layed on a design, which is safe, simple and suitable for manufacturing by the danish industry.

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CONTENTS

1. INTRODUCTION

This report contains a description of a proposed design concept of a nuclear reactor for district heating. Emphasis has been layed on a design, which is simple and suitable for manufacturing by the danish industry.

No economic evaluation has been performed of a district heating plant with the proposed reactor. However, it is expected, that the simplicity in its design will result in a low heat cost and make it competitive with fossil plants even on a small scale.

It must be noticed, however, that the proposed design concept is only very preliminary. Thus certain changes of the design may prove to be necessary as a result of a detailed design or safety analysis.

2. NUCLEAR REACTORS FOR DISTRICT HEATING

2.1. General

The interest in district heating by nuclear power is growing in several countries. Three projects have been worked out: The SECURE in Sweden (in cooperation with Finland), THERMOS in France and DHAPP in USSR (see ref.). The main data for these projects are presented in Table 1.

Table 1. Main data for nuclear district heating projects.

	SECURE	THERMOS	DHAPP
Capacity, MW	200	100	500
Primary system			
Pressure bar	7	8	13
Inlet temp. °C	90	130	167
Outlet temp. °C	115	140	190
Reactor core			
Uranium t	13	2.7	-
Enrichment %	2.6	3.5	-
Heat rate W/gU	15	37	-
District heating water			
Flow temp. °C	95	120	150
Return water temp. °C	60	80	70

The district heating plant utilizes the heat from the reactor almost 100% and needs no cooling water. This is of importance for the environment and gives more possibilities for site selection. Further, contrary to fossil fuel fired plants, such a plant does not pollute the atmosphere by combustion products and does not need transportation and storage area for huge amounts of fuel. Thus the nuclear district heating plant is highly attractive with respect to its environmental impact. Due to the low power output, operating pressure and -temperature, the reactor plant can be built as a very simple and safe device, with no need for advanced heavy industry for its fabrication. In a country like Denmark the major part of a nuclear district heating power plant can be built by domestic industry.

A characteristic feature for the three projects mentioned above is that the nuclear fuel is surrounded by a large volume of water, which assures a quick and effective cooling in case of accidents.

Calculations performed in connection with the SECURE and THERMOS projects indicate, that plants of the sizes selected in Table 1 for cities with 50.000 to 100.000 inhabitants should be competitive with oil fired district heating plants. Furthermore the cost of heat from nuclear district heating plants will be less sensitive to possible increases in fuel costs since the fuel costs constitute a smaller fraction of the heat cost in these plants than in conventional district heating plants.

3. OUTLINE OF PROPOSED DESIGN CONCEPT

The reactor is outlined in Fig. 1. The reactor consists of a pool, lined with stainless steel. The pool is surrounded by concrete, which supports the pool and provides biological shielding. Thermal insulation is placed between liner and concrete. The reactor pool is not pressurized, and during normal operation the lid is connected to the vent system.

The reactor pool contains the reactor core (pos. 1) and associated piping, the control rod guide tube (pos. 2), the cooling coils (pos. 3) and the bottom plate (pos. 4) with check valves (pos. 5).

The reactor core consists of fuel elements of a design similar to normal LWR fuel elements or plate type elements.

The reactor core is placed within a structure, which is surrounded by a thermal insulation (pos. 6).

The reactor core is connected to a primary cooling system, consisting of two circuits, each with a heat exchanger and a circulation pump. The piping for one of the primary cooling circuits is shown in Fig. 1 (pos. 7). The piping is thermally insulated from the pool water.

Two secondary circuits (not shown) are provided, each with a circulation pump and a heat exchanger. The secondary sides of these heat exchangers are connected to the district heating system.

The reactor can be designed for control either by control rods, by means of boron solution in the primary coolant or by both.

For the purpose of cooling the reactor pool various cooling coils are mounted in the pool (pos. 3).

Check valves (pos. 5) in the bottom plate (pos. 4) serve the purpose of directing the coolant through the reactor core during normal as well as abnormal conditions (natural circulation).

The dimensions of the reactor will of course depend on the required heat capacity of the plant. The required water head above the primary piping outlet from the pool depends on the temperature of the primary coolant at the outlet from the reactor core. A water head of 12 m will correspond to a max. reactor core outlet temperature of approximately 115°C.

4. NORMAL OPERATION

4.1. Start of the Reactor

Before the reactor is started, the check valves (Fig. 1, pos. 5) are closed. A check valve is shown in Fig. 2. The check valves are closed hydraulically, by starting a centrifugal pump (Fig. 1, pos. 8). This pump delivers pool water at a certain overpressure - relative to the pool - to the bellow housing inlets (Fig. 2, pos. 1) causing lifting of the valve bodies and closing of the valves.

After closing the check valves the primary coolant pumps are started. This creates a flow through the core, and the corresponding pressure drop across the core will keep the check valves closed.

After starting the primary coolant pumps, the valve closing pump is stopped. For obvious safety reasons this must be properly assured.

4.2. Normal Operation

At normal operating conditions the plant delivers heat to the district heating network as required. The reactor power level is adjusted accordingly by the reactor control system, either by means of control rods or by means of the concentration of boron in the primary coolant. The heat is generated in the reactor core and is transported from there to the district heating network by means of the primary and secondary cooling systems.

Preliminary calculations have shown that during normal operation the reactor will be in a safe condition,and ample safety against burnout can easily be obtained.

As described in section 4.1 above,the check valves in the bottom plate are kept closed during normal operation by the primary coolant pressure drop across the core. This prevents the primary coolant from bypassing the reactor core through the annulus between the reactor core and the reactor pool liner.

The temperature of the reactor pool both above and below the bottom plate is kept at a low level (∿30-50°C) by means of cooling coils.

The temperature of the primary coolant is kept at a level corresponding to the temperature requirements of the district heating network and the temperature differences across the heat exchangers.

The boron concentration of the pool water above as well as below the bottom plate is kept at a relatively high level (see section 5 below).

The boron concentration in the primary coolant is lower than in the pool or zero, depending on whether the reactor is controlled by boron or by control rods. For this reason the reactor core must be thermally insulated from the reactor pool and the primary coolant must be hydrodynamically separated from the pool water by barriers at the top and bottom of the reactor core (Fig. 1, pos 9).

4.3. Normal Reactor Shut down

Under normal conditions the reactor is shut down by insertion of the control rods into the reactor core or by increasing the boron concentration of the primary coolant, depending on the design of the control system.

An alternative reactor shut down method would be to stop the primary circulation pumps and thereby initiate an automatic shut down and cooling by the pool-water as described in section 5.

After shut down the residual heat is removed either by the primary cooling system or by natural circulation in the reactor pool. The residual heat can be dissipated to the environment via a cooling tower.

5. ABNORMAL CONDITIONS

5.1. Loss of Flow

In case of failure of one of the primary circulation pumps during operation, the reactor can be operated at reduced power, if this is desirable, by using the intact circulation pump and the corresponding primary and secondary circuits.

In case of failure of both primary circulation pumps, the pressure drop across the core will disappear. This will cause the check valves (Fig. 1, pos. 5) to open by gravity, thereby permitting a natural circulation through the reactor core of cold pool water with a high concentration of boron. Thus when the forced circulation through the core vanishes, the reactor will be stopped and cooled by pool water, automatically.

However, it is possible, that a detailed analysis of this transient will prove, that unacceptable conditions will occur in the reactor core. If so, the conditions can be improved by connecting the lower plenum to a tank containing cold, highly borated water above the reactor pool by a pipe without valves. During normal operation the water level will be higher in this tank than in the reactor pool corresponding to the pressure drop across the core. In case of failure of both primary circulation pumps, the tank will immediately introduce cold, highly borated water into the reactor core, and thereby automatically shut down the reactor in the initial part of the natural circulation cooling phase.

Cooling of the pool will normally be done by any of two independent cooling coils in the pool. Each coil can be connected to a cooling tower or to an "ad hoc" cooling system through flanges, external to the reactor containment building.

However, since the water in the pool is kept at a low temperature, the pool can easily be designed with sufficient heat capacity in itself to absorb the residual heat from the reactor for several hours without any cooling of the pool before the boiling point of the water is reached.

5.2. Leakage in the Primary System

A sudden leakage in the unpressurized reactor pool structure must be considered as an event, which will occur with a negligible frequency compared to leakages in the pipe system.

In case of a leakage in the pipes penetrating the reactor pool wall, the pool cannot be emptied below the point of penetration, which must be above the top of the reactor core structure (Fig. 1). This of course will also require, that the entire primary system is arranged at or above that level. As shown in Fig. 1 cooling coils can be arranged in the lower part of the pool in order that it can be cooled even under such circumstances. However, if required, the entire external part of the primary system can be arranged within a watertight structure with such a small volume, that the water level in the pool will only be lowered acceptably in case of a leakage in the external primary system.

5.3. Failure of the Power Supply

As in nuclear power plants for electric power production, if the auxiliary power system fails, an emergency system will take over the necessary supply for instance: Instrumentation, control, emergency light and the power supply for one of the two main- and secondary pumps, and a cooling tower fan and -circulation pump.

6. ADDITIONAL ANALYSES

As has been mentioned, the proposed reactor design concept is only very preliminary, thus no detailed design or safety analysis have been performed; this of course will be necessary in connection with possible plans for making detailed design studies.

In connection with further studies it is very likely,that many safety aspects can be analysed by very simple experimental facilities, since the proposed reactor operates at very low temperature and pressure.

REFERENCE

Topical Meeting on LOW TEMPERATURE NUCLEAR HEAT Otaniemi, Finland, August 21-24, 1977. Sponsored by The Finnish Nuclear Society, The European Nuclear Society and The American Nuclear Society.

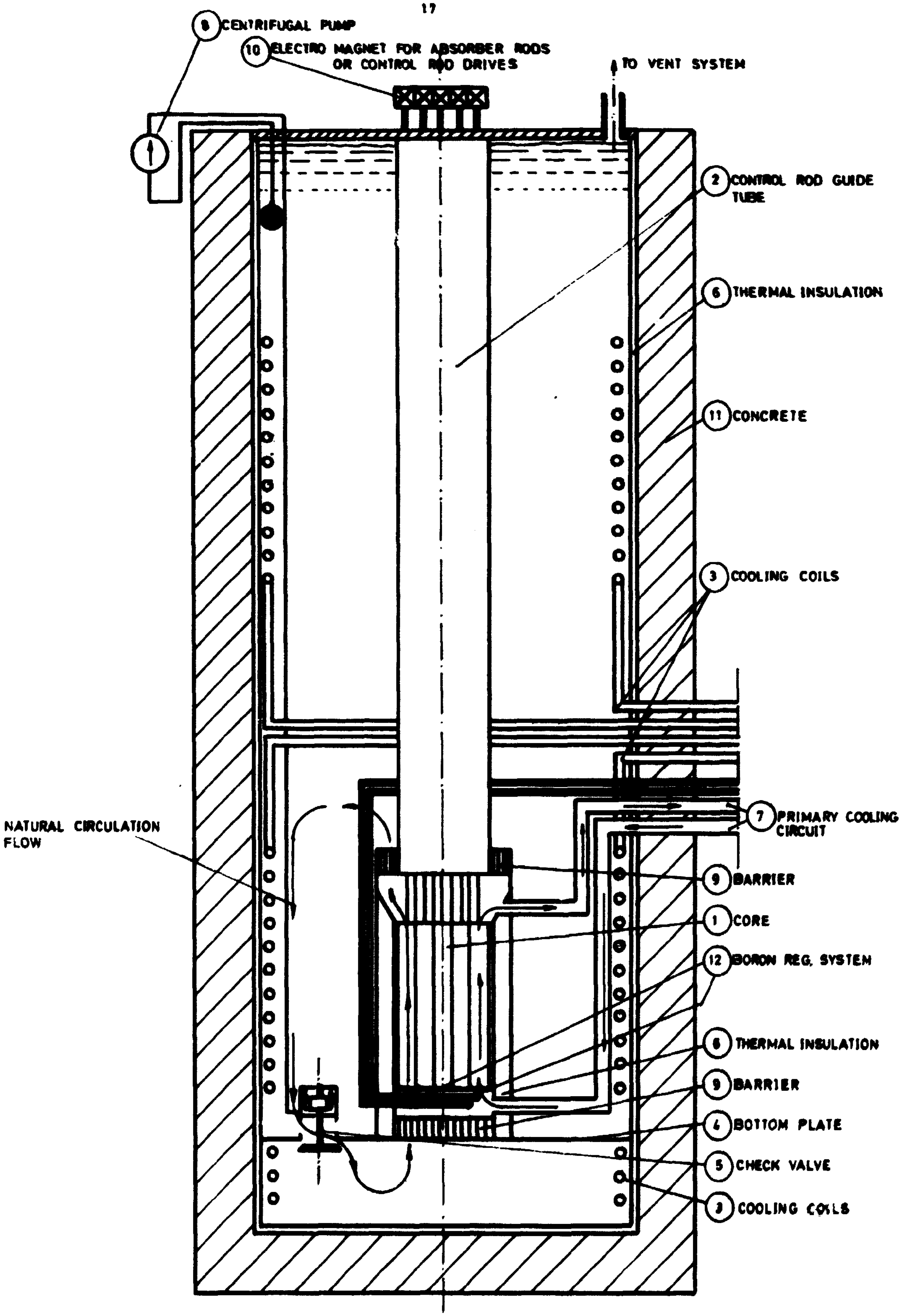

FIG.1. REACTOR POOL WITH INTERNALS.

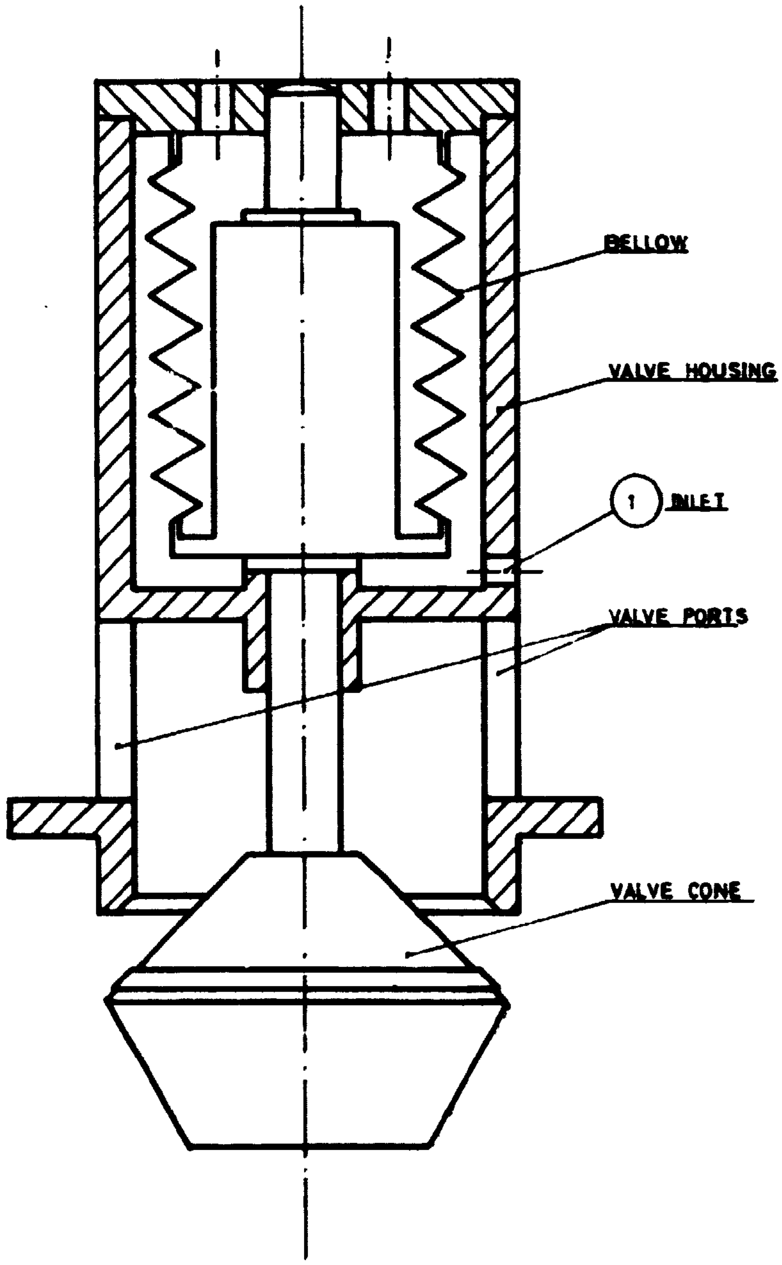

FIG. 2. CHECK VALVE.